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The environmental feasibility of algae biodiesel production

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Abstract Microalgae can grow in waste or seawater, have vastly superior biomass yields per hectare and, most importantly, the CO_2 removed from the atmosphere during photosynthetic growth of the plant offsets CO_2 released during fuel combustion. Algae-based fuel products are more promising than first-generation biofuels, as they exclude land use and food security issues, but require a mass production breakthrough to be viable. Through a life cycle approach, we evaluate whether algal biodiesel production can be a viable fuel source once the energy and carbon intensity of the process are managed accordingly. Currently, algae biodiesel production is 2.5 times as energy intensive as conventional diesel. Biodiesel from advanced biomass can only realize its inherent environmental advantages of GHG emissions reduction once every step of the production chain is fully optimized and decarbonized. In the case of Saudi Arabia which operates on a 100 % fossil-based electricity and heat grid, the inherent environmental advantages of producing algae biodiesel would be heavily overshadowed by the nation's carbon-intensive energy and power sector.

Keywords Algae biodiesel · Lifecycle analysis · Carbon footprint · Cumulative energy demand · Energy security · Renewable energy

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The search for alternative fuels for the transport industry has revived the interest in biofuels from sustainable cultivation and feedstock which is not in competition with food or animal feed [1]. While biofuels remain a viable alternative to fossil fuels, a full replacement of our 90 % hydrocarbon-based transport industry is unlikely in the near to mid-term future [2–8]. With the emphasis shifting towards the development of advanced biofuels, microalgae has proven to be a promising feedstock to overcome land use and food security issues while growing in waste or seawater [7, 9–11]. The oil-rich algae biomass, with its superior production yields [12–14] has attracted considerable attention as potential domestic and renewable substitute for imported fossil fuels. Given microalgae's high production yields, the required global land mass necessary to satisfy global fossil fuel consumption could be considerably reduced. For algae-derived biodiesel with a yield of 850 GJ/ha/year, to replace the total production of 748 million tons of petroleum-derived diesel in 2009, a land mass of around 57.3 million ha would be required. This land size approximated to an area somewhat smaller than Texas [7]. The inherent potential advantage of biodiesel production from algae is lower lifecycle Greenhouse Gases (GHG) emissions, as algae biomass converts atmospheric CO_2 through photosynthesis into bio-plant material which is eventually released back to the atmosphere via micro-organisms when used as a fuel, via engine tail pipe emissions [10, 15, 16]. Fossil fuel combustion releases additional carbon which took million of years to be removed from the atmosphere [17]. Moreover, compared to cultivation requirements for other advanced biofuel sources microalgae growth mainly requires solar radiation, carbon dioxide, water and nutrients in the form of inorganic salts [18]. Given an existing base of 50,000 species of known microalgae, only a fraction is appropriate for biodiesel

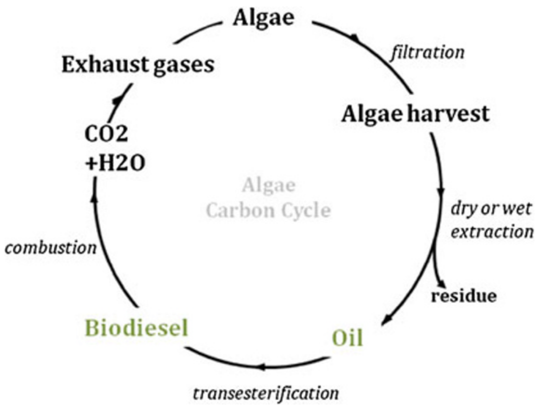

Fig. 1 Algae to biodiesel carbon cycle [7]

production, due to algae strains' varying lipid content and productivity levels [10, 19]. On average algal lipid content varies between 20 and 50 % by weight of dry biomass, although some strains can under certain optimally induced conditions accumulate as much as 90 % oil yield ratios [18, 20, 21].

Microalgae is cultivated in either open raceway ponds or closed photobioreactors (PBR), each of which has been designed in a variety of operating configurations [10]. Both farming approaches are still held back by substantial technical and economic hurdles. Although photobioreactors benefit from higher productivity rates, lower evaporative water losses or likelihood of culture collapse, the farming approach is still challenged by its significantly larger capital investment and operating cost base [9, 22]. While open pond algae cultivation is operated on a 60–100 % lower cost level, the technology is held back from its large-scale commercial breakthrough by problems of poor light utilization efficiency, lower volumetric productivity and higher risk of culture contamination or collapse [10, 19, 22, 23]. However, since this industry is not mature, there is ample space for optimization and we expect the future rise in oil prices to add to this effect.

The main stages of the algae biodiesel production process consist of algae farming, biomass harvesting, oil extraction, transesterification of algae oil, fuel distribution and combustion, see Fig. 1.

As part of our LCA study, microalgae batches are cultivated in open pond farming installations, harvested and dried in subsequent stages to generate 75 tonnes/ha/year of dry algae biomass. The extracted 30 % share of algae lipids (22.5 tonnes/ha/year) is further transesterified to yield 850 GJ/ha/year of biodiesel. 89 GJ/ha/year of glycerol is generated as a by-product and is exported as animal feed. The remaining 70 % residual algae biomass (689 GJ/ha/year) is used in various co-product utilization methods to offset the production process' substantial energy requirements. When we consider all energy inputs of the biodiesel production cycle as 100 % fossil fuel sourced, the production process is 2.5 times as energy intensive as conventional diesel from the United States and nearly equivalent to the high fuel-cycle energy use of oil shale diesel, see Fig. 2. The major disadvantage inherent in biodiesel production from microalgae is driven by the high energy input in the form of heat and electricity.

Biodiesel from algae biomass can only realize its inherent environmental advantages of GHG emissions

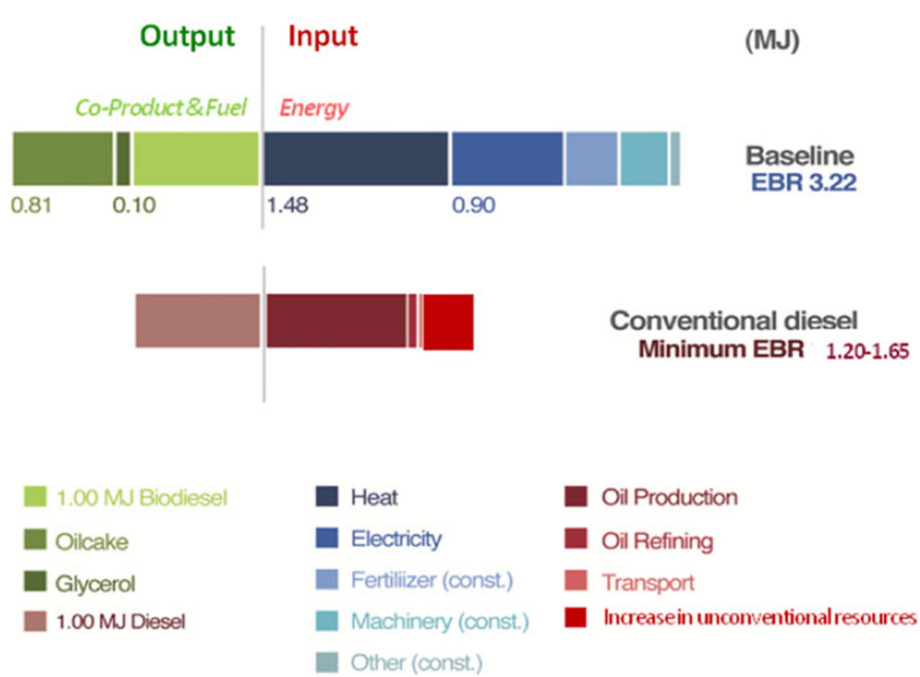

Fig. 2 Benchmarking the life cycle energy requirements of fossil fuels against algae biodiesel [7]

reduction, once every step of the production chain is fully optimized and decarbonized. This will entail the sourcing of all direct energy input in the form of heat and electricity, as well as indirect requirements for transport and building materials, from low-carbon energy sources. Moreover, the offset of carbon-intensive fertilizer requirements through the recycling of wastewater will be critical. Recent studies suggest that without the recycling of harvest water, the algae-to-biodiesel water footprint is as high as 3,726 kg water/kg biodiesel [11]. Further improvements in the production of cycle's carbon footprint can be achieved through the commercialization of new oil extraction technologies. By eliminating the need to dry algae biomass to a 90 % solid content [13] required for the subsequent oil extraction in vegetable oil mills, considerable energy savings could be achieved.

As a priority, countries will need to defossilize primary energy sources used by their electricity grids, as only then can the transport sector move towards low GHG emissions. In the case of Saudi Arabia which operates on a 100 % fossil-based electricity and heat grid, the inherent environmental advantages of producing algae biodiesel would be heavily overshadowed by the nation's carbon intensive energy and power sector. In contrary, Brazil and France, which essentially operate on a defossilized electricity grid, have the potential for biodiesel from algae to be a viable alternative to conventional diesel [7]. Ultimately with the transport fuel industry remaining to be fuelled by hydrocarbons for the foreseeable future, biofuels will need to contribute as well as complement our current fuel mix as part of a larger mission to diversify our global transport system within the mid-to long-term future.

References

1. Gallagher E (2008) Renewable fuels agency. East Sussex, UK
2. Alekkett K (2007) OECD/ITF Joint Transport Research Centre. Discussion Papers
3. Campbell JE, Lobell DB, Genova RC, Field CB (2008) The global potential of bioenergy on abandoned agriculture lands. Environ Sci Technol 42:5791–5794
4. Owen NA, Inderwildi OR, King DA (2010) The status of conventional world oil reserves—Hype or cause for concern? Energy Policy 38:4743–4749
5. Sperling D, Gordon D (2009) Two billion cars: driving toward sustainability. Oxford University Press, USA
6. Wells J (2007) Crude oil: uncertainty about future oil supply makes it important to develop a strategy for addressing a peak and decline in oil production. DIANE Publishing, Darby
7. Shirvani T, Yan X, Inderwildi OR, Edwards PP, King DA (2011) Life cycle energy and greenhouse gas analysis for algae-derived biodiesel. Energy Environ Sci 4:3773–3778
8. King D, Inderwildi O (2010) Future of mobility roadmaps, smith school of enterprise and the environment. University of Oxford, Oxford
9. Jorquera O, Kiperstok A, Sales EA, Embiruçu M, Ghirardi ML (2010) Comparative energy life-cycle analyses of microalgal biomass production in open ponds and photobioreactors. Bioresour Technol 101:1406–1413
10. Mata TM, Martins AA, Caetano N (2009) Microalgae for biodiesel production and other applications: a review. Renew Sustain Energy Rev 14(1):217–232
11. Yang J, Xu M, Zhang X, Hu Q, Sommerfeld M, Chen Y (2011) Life-cycle analysis on biodiesel production from microalgae: water footprint and nutrients balance. Bioresour Technol 102:159–165
12. Clarens AF, Resurreccion EP, White MA, Colosi LM (2010) Environ Sci Technol 44:1813–1819
13. Lardon L, He lias A, Sialve B, Steyer JP, Bernard O (2009) Life-cycle assessment of biodiesel production from microalgae. Environ Sci Technol 43:6475–6481
14. Schenk PM, Thomas-Hall SR, Stephens E, Marx UC, Mussgnug JH, Posten C, Kruse O, Hankamer B (2008) Bioenergy Res 1:20–43
15. Pickett J, Anderson D, Bowles D, Bridgwater T, Jarvis P, Mortimer N, Poliakoff M, Woods J (2008) Sustainable biofuels: prospects and challenges. The Royal Society, London
16. Wang MQ (1999) GREET 1.5-transportation fuel-cycle model: methodology, development, use, and results, ANL/ESD-39, vol 1. Argonne National Lab, IL
17. Sheehan J, Camobreco V, Duffield J, Graboski M, Shapouri H (1998) Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus. Final report, National Renewable Energy Lab., Golden
18. Chisti Y (2007) Biotechnol Adv 25:294–306
19. Richmond A (2007) Handbook of microalgal culture: biotechnology and applied phycology. Blackwell, Oxford
20. Li Y, Horsman M, Wang B, Wu N, Lan CQ (2008) Effects of nitrogen sources on cell growth and lipid accumulation of green alga *Neochloris oleoabundans*. Appl Microbiol Biotechnol 81:629–636
21. Li Y, Horsman M, Wu N, Lan CQ, Dubois-Calero N (2008) Biofuels from microalgae. Biotechnol Prog 24:815–820
22. Pulz O (2001) Photobioreactors: production systems for phototrophic microorganisms. Appl Microbiol Biotechnol 57:287–293
23. Carvalho A, Malcata FX (2006) Microalgal reactors: a review of enclosed system designs and performances. Biotechnol Prog 22:1490–1506